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Abstract

Title: Enhancing Dependability in Cyber-Physical Renewable Energy Systems

Cyber-physical renewable energy systems (RESs), comprising wind turbines, solar photovoltaic (PV) arrays, and batteries integrated into microgrids, form the backbone of the next-generation electricity grid, commonly referred to as the “smart grid.” Enhancing the dependability (safety, security, reliability, availability, and resilience) of these RESs, both on the physical and cyber fronts, demands innovative approaches for physical-faults and cyber-attacks monitoring and fault-tolerant and attack-resilient control. Despite their distinct origins, both faults and cyber-attacks can have comparable consequences, leading to increased operating costs, physical damages, and potential cascading failures. Swift identification and differentiation of these incidents are essential to implement timely corrective actions and limit system damages.

This tutorial focuses on the critical importance of early detection, diagnosis, and mitigation of physical-faults and cyber-attacks in cyber-physical RESs and microgrids to facilitate their dependable operation towards a future goal of electrification for resilient and decarbonized systems and communities fighting with climate change and global warming. Recent advancements in digitalization and the Industrial Internet of Things (IIoT) have enabled robust intrusion detection and cyber-attack mitigation countermeasures, offering unprecedented advantages. Moreover, the tremendous computational power available in modern computers has propelled artificial intelligence (AI) and advanced machine learning capabilities to new heights. Leveraging these developments, we can efficiently convert vast and multidimensional sensor data into valuable insights, enabling intelligent monitoring and reliable control of energy and power systems.

The tutorial delves into the following key objectives:

- Explore the critical challenges associated with physical-faults and cyber-attacks in RESs within microgrids and smart grids;

- Introduce existing techniques and tools for condition monitoring, control, and health management of wind turbines and solar PV systems in microgrids;
- Present an in-depth review of state-of-the-art techniques for condition monitoring, fault-tolerant control, and attack-resilient control of wind turbines and solar PV systems in microgrids;
- Illustrate practical design approaches through several comprehensive case studies;
- Discuss important challenges, unresolved issues, and outline future directions in this dynamic and burgeoning research and development domain.

- Duration:

The tutorial will last for 90 minutes (1.5 hours). The timing of each presentation is detailed in the next section (i.e., Outline).

- Outline:

The tutorial will include the following 5 main sections in line with the overall theme of the tutorial.

1) "Introduction to the Tutorial Session" (15 minutes incl. Q&A: Prof. Zhang)

In this presentation, the content of tutorial will be outlined and the broad areas of condition monitoring, fault-tolerant and attack-resilient control will be introduced and discussed.

2) "Condition Monitoring of Wind Turbines and Wind Farms" (25 minutes incl. Q&A: Prof. Badihi)

The presentation begins with an introduction to individual wind turbine and entire wind farm condition monitoring including new and emerging state-of-the-art techniques and tools. Then, it continues with two case studies for wind turbines and wind farms including detailed design and implementation steps.

3) "Fault-Tolerant and Attack-Resilient Control of Wind Turbines" (20 minutes incl. Q&A: Prof. Zhang)

This presentation begins with the classifications and objectives of control at both individual wind turbine and entire wind farm levels; covering wind turbine performance and fatigue load control, as well as wind farm power quality and power dispatch control. In continuation, various passive and active fault-tolerant control approaches and attack-resilient control schemes in wind turbines and wind farms will be discussed with three case studies.

4) "Attack-Resilient Control of Solar PV Systems in Microgrids" (20 minutes incl. Q&A: Prof. Badihi)

This presentation begins with an introduction to microgrids and the role of solar PV systems in them. The possible physical-faults and cyber-attacks related to PV systems will be detailed and analysed. Accordingly, various schemes under different case studies will be presented to demonstrate the diagnosis and mitigation of physical-faults and cyber-attacks in hybrid microgrids with solar PV integration.

5) "Summary, Discussion, Open Problems, Future Issues, and Feedback" (10 minutes: Prof. Zhang, and Prof. Badihi)

Lastly, the tutorial will be closed with a summary and discussion on the open problems and future directions in this field.

- Motivation and Focus:

The proposed tutorial addresses an interesting and active research topic related to the important aspects of safety, security, reliability, availability, and resilience of cyber-physical renewable energy systems in evolving smart grids. It enhances technical information exchange and transfer, which also plays an important role to keep the researchers up-to-date with the latest developments in this field. In terms of intended audience, the tutorial is oriented towards graduated students, researchers and engineers/practitioners from both academia and industry, who are interested in cyber-physical renewable energy systems, microgrids and smart grids and in learning more about condition monitoring, health management, advanced fault-tolerant and attack-resilient control, and their applications in energy and power systems. The tutorial is also suitable for any academic faculty in the field of energy and power who would like to become more familiar with condition monitoring and control theories and applications.